Investigation of optimal thermal parameters for essential oils extraction using laboratory and solar distillation systems

A. Munir, O. Hensel

(*Department of Agricultural Engineering Nordbahnhofstr. 1a, University of Kassel*, 37213 *Witzenhausen, Germany*)

Abstract: Essential oils are used in medicines, foods, fragrances, perfumery and cosmetics etc. Different methods are used for essential oils extraction. Out of all these methods, distillation methods have advantage of extracting refine essence of the plant materials and herbs by evaporating volatile components. The main object of the research is to investigate optimal thermal parameters and to develop simple and best methodologies for easy adaptation of these techniques for decentralized applications. The research for essential oils extraction was conducted under laboratory conditions and by using solar energy. For each laboratory experiment, equal weights of the herbs were used. The energy consumption for different herbs was recorded with the help of energy meters and process curves were drawn for comparison. The heat energy consumption to extract one milliliter of essential oil from Cloves buds, Fennel, Cumin, Patchouli, Cassia and Orange barks was found to be 0.133, 0.503, 0.574, 2.716, 2.807 kWh respectively. The methodology and thermal parameters provide useful information regarding temperature and energy requirements to process different herbs. On the basis of laboratory results, a de-centralized solar distillation system was developed using Scheffler reflector (8 m^2 aperture area) and evaluated. The power and system efficiency of solar based system was found to be 1.58 kW and 43.25% respectively. Successful results were obtained for essential oils extraction from herbs by using solar energy. These results were found similar to that of laboratory showing that the solar energy can be effectively used for the distillation of essential oils.

Keywords: Essential oils, herbs, scheffler reflector, solar distillation

Citation: Munir A., and O. Hensel. Investigation of optimal thermal parameters for essential oils extraction using laboratory and solar distillation systems. Agric Eng Int: CIGR Journal, 2010, 12(1): 107—114.

1 Introduction

Essential oils and aromatic plants have long been used since a long time throughout the world in medicines, foods, fragrances, cosmetics etc. In the last decade, these potent natural remedies have gained enormous popularity in industrialized countries as well particularly in the multi-million-dollar aromatherapy business. Essential oils are extracted from various parts of the plant like leaves, roots, wood, bark, seeds/fruits, flowers, buds, branches, twigs, or whole plants (Öztekin and Martinov, 2007). A single ounce of most essential oils has worth thousands of dollars. Different techniques are used for essential oils extraction like hydro & steam distillation, cold pressing/expression, maceration and solvent extraction etc. Out of all these methods, the distillation methods have advantage of extracting pure and refine essential oils by evaporating the volatile material (Malle and Schmickl, 2005). Some essential oils come from extremely delicate flowers that must be processed soon after harvesting. Thus, for functional and economic reasons, there is need for small-scale, decentralized steam distilling equipment. Examples of plants that are distilled, are Cumin, Cloves, Anise, Caraway, Cassia, Patchouli, and Fennel etc.

The establishment of herb production venture involves relatively high capital investment, particularly for plant material, irrigation, machinery and distillation or drying equipment. Therefore, there is high level risk

Received date: 2009-03-12 **Accepted date:** 2010-03-10

Corresponding author: A. Munir, PhD candidate, Email: anjum.munir@uni-kassel.de. **O. Hensel**, University of Kassel, Department of Agricultural Engineering. Nordbahnhofstr. 1a, 37213 Witzenhausen, Germany.

involving in setting up a venture based herbal production. The level of risk declines as the industry developing, production technology increasing, markets are defined and an industry infrastructure is established (Bruce 2001). The main object of the paper is to develop and promote simple and best methodologies for easy adaptation of these techniques for small scale and decentralized applications. The paper presents the research work conducted for essential oil extraction with laboratory apparatus and field distillation system by using solar energy.

Various industrial surveys show that up to 24% of all industrial heat, directly used in the process, is at temperature below 180℃. In remaining 76%, considerable amount of heat can be supplied for preheating up to 180℃. About 40% of all process heat is in the temperature range from ambient to 180℃. In several industries, 100% process heat requirement is below 180℃, which can be supplied economically by evacuated tube collectors and solar concentrators and makes the solar system attractive (Garg and Prakash, 2006). Most of the agro-based industries lie in this medium temperature range. The maximum flux of incident radiant energy available is approximately 1,100 W/m^2 without optical concentrating (Duffie and Beckman, 2006). Although various kinds of solar collectors are in use yet their applications are restricted by drying and low temperature water boiling for heating houses and swimming pools etc. A study conducted for the “Energy Research and Development Administration” by the “Inter Technology Corporation” indicated that solar energy has the potential of providing about 20% of total energy. The economic outlook for industrial solar heat appears to be extremely favorable because process heat solar collector could be used throughout the year and each system could be designed to fit the temperature level required for its specific application, which is particularly important in the use of process (Goswami, Kreith and Kreider, 1999).

Several experiments were carried out to utilize the solar energy in medium temperature range using vacuum tube collectors with integrated circuits to increase the temperature in medium-high temperature range (Sharma, Iwata and Kitano, 2005; Stumpf and Balzar, 2001; Morrison, Di and Mills, 1993; Esen 2004; Balzar et al, 1996). These vacuum collectors are efficient in low temperature range but not suitable for continuous processing in medium-high temperature range due to more heat losses by increased exposed area. Decreasing the area from which the heat losses occur can increase energy delivery temperature. With higher concentration ratio, there is increase in temperature at which heat is delivered. It is observed from the comparison that the two axes tracking paraboloidal dish, which always faces the sun, is the most promising design for the concentrating systems justifying the use of Scheffler concentrator for industrial process heat applications (Bhirud and Tandale, 2006). These concentrators also provide automatic tracking system. These concentrators are capable of delivering temperature in the range of 300 ℃ and are technically suitable for medium temperature applications (Delaney, 2003). The utilization of solar energy in small scale agro-based industries in the domestic sector can reduce their high cost of production by saving fuels and reduce environmental pollution. The on-farm extraction techniques using “Scheffler Solar Concentrator” also provide an extraordinary opportunity to extract the fresh herbs at farm level. Keeping all facts in view, the research has been initiated to investigate the optimal thermal parameters for essential oils extraction from herbs using laboratory experiments and innovative form of solar renewable energy in the field of post harvest processing.

2 Materials and methods

The research comprises of two phases, laboratory experiments with small scale distillation system followed by field experiments using solar energy.

2.1 Laboratory experiments

Laboratory experiments were conducted using small scale distillation units. The apparatus comprises of insulated electric heaters (0-500 W), round glass boilers, each having two liters capacity, glass still tube and counter current flow glass condensers as shown as Figure 1.

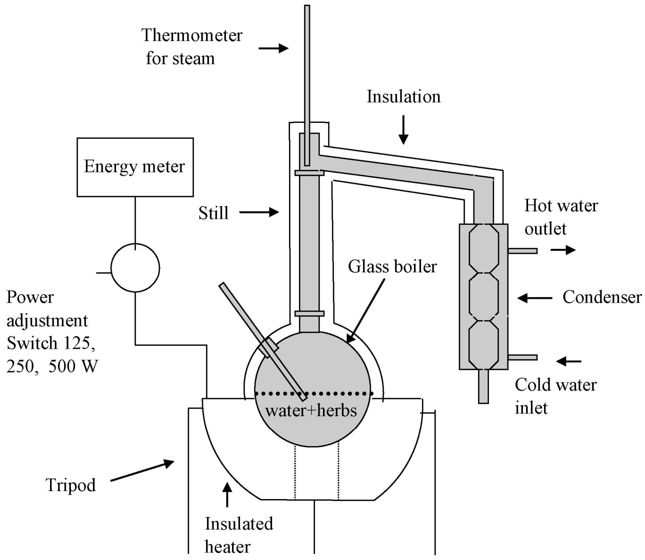

Figure 1 Detail of laboratory distillation apparatus

The laboratory distillations units were completely insulated to eliminate the effect of heat losses. In each experiment, 100 g of the herbs were used. The electric connections to the heaters were provided through energy meters. In the process, the water vapors along with volatile essence of the plant material flow through still vessel and then condensed. The condensate is then collected in a Florentine flask where oil is separated from hydrosol due to specific weight difference. Identical conditions were maintained during experiments for different herbs. Energy meters (Error < ± 0.1%) and thermometers (Error < ± 0.1 K) were used to record real time data to investigate the optimal thermal and physical parameters during the distillation of essential oils. The laboratory data leads in design and development of solar distillation unit.

2.2 Scheffler reflector

The Scheffler reflector is installed at "Solar campus" University of Kassel, Witzenhausen. The experiments were conducted during summer 2007. The Scheffler concentrator comprises of a primary reflector, a secondary reflector and a tracking device (photovoltaic or clock mechanism powered by gravity). The primary reflector has 8 m^2 aperture area and produces a converging beam of sunlight on the secondary reflector having 0.434 m^2 surface area. Highly secular aluminium sheets were used to meet the requirements for medium concentrating technologies. They offer solar weighted reflectance of 88%–91%, good mechanical properties and are easy to recycle (Fend, Jorgenson and Kuster, 2000). The tracking device actuates the primary reflector and keeps the reflected beam aligned at a fixed secondary reflector as the sun moves. The fixed secondary reflector further reflects the beam radiations onto a targeted heating spot. Each morning, the primary reflector has to set back to a starting position in which the secondary reflector is illuminated to start the tracking work. After a few days, the angle between the axis of rotation and the reflector is to be adjusted to accommodate the seasonal variation in the height of the sun. The above mentioned whole system is oriented in North–South direction. The latitude angle for Witzenhausen is set at 51.3^o. The solar distillation system is shown in Figure 2.

Figure 2 Solar distillation system for essential oils extraction using Scheffler reflector

2.3 Experimental setup

On the basis of results obtained from laboratory experiments and from evaluation of Scheffler reflector, the distillation unit was fabricated. A cylindrical steel tank of 40 L capacity was selected as a boiler. A pipe connects the top of the boiler to a condenser. A Florentine flask with 200 mL capacity was used to separate the oil from hydrosol. In order to assess the continuous performance of the Scheffler reflector during distillation experiments, three connections of K-type and T-type thermocouples were used to record receiver inside temperature, water temperature and steam temperature of the distillation unit. All the three connections were attached to compute via data logger. The intensity of solar radiations was recorded with the help of Pyranometer.

3 Results and discussion

3.1 Laboratory experiments

In order to evaluate the performance of solar based system, it is necessary to perform laboratory experiments simultaneously under similar conditions to compare the results. Unlike other food and post harvest processing, distillation experiments for essential oils extraction are energy and temperature sensitive due to presence of volatile component in the plants. The laboratory experiments provide useful information about optimum thermal and physical parameters for different kinds of herbs. The conversion factor of electric heater (from electrical energy to heat energy) was also calculated and found to be 0.667 in the steady state temperature range. This conversion factor is calculated by taking average of six readings of heat energy (kWh) calculated in steady state sensible heat range (30-65℃) using water divided by the electrical energy recorded from energy meter. The steady state range is taken to avoid the influence of heat absorbed in vessel walls at the start of experiment and slight evaporation of water above 70℃. Process curves were drawn for different herbs for essential oils extraction (mL) against total heat energy consumed (kWh). Process curves for Fennel, Cumin and Cloves are shown in Figure 3.

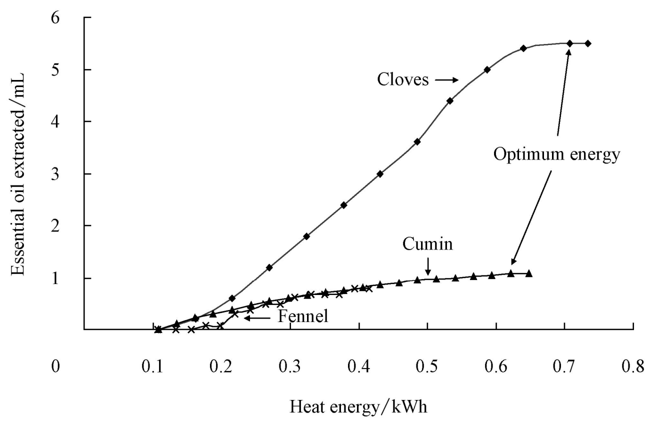

Figure 3 Process curves for different herbs

It is clear from Figure 3 that different herbs have different contents of oils and require different quantities of energy consumption during distillation of essential oils. It depends on the oil contents, time of harvesting, moisture contents and part of the plant used etc. It is also evident from Figure 3 that there is gradual increase in oil extraction in latent heat phase. At a specific energy level, there is no further increase in essential oil contents and the line becomes parallel to abscissa. The experiments were carried out for longer range of energy to see further effect (not shown in the graph). For each herb, there is a specific energy level at which 100% of essential oil is extracted. Similarly, the optimum energy levels for different herbs were recorded. The other parameters like plant condition, moisture contents, harvesting time etc were also recorded simultaneously. Optimum energy consumption to process 100 g of Cloves buds, Fennel, Cumin, Patchouli and Orange barks was found to be 0.734, 0.394, 0.621, 0.440 and 0.379 kWh respectively as shown as Figure 4.

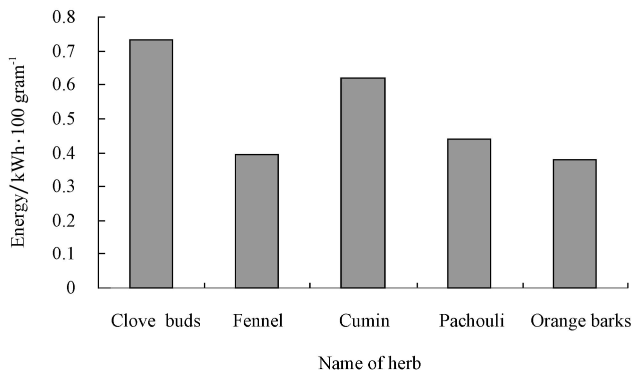

Figure 4 Optimum energy required per 100 g of different herbs

Laboratory results conclude that fresh herbs need short duration for processing and are less energy consumption. From the recorded data, energy required to extract one milliliter of the oil was calculated. The heat energies required to extract one milliliter of essential oil from Cloves buds, Fennel, Cumin, Patchouli, Orange barks was found to be 0.133, 0.503, 0.574, 2.716 and 2.807 kWh respectively as shown as Figure 5.

These results provide useful information in adopting appropriate distillation parameters to process the herbs at farm. These results also lead in the development of solar distillation system.

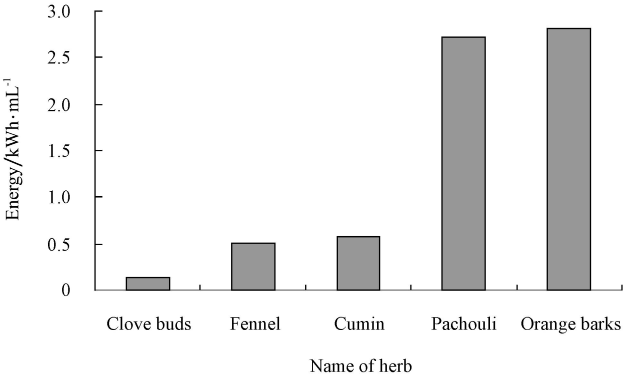

Figure 5 Optimum energy required to extract one milliliter of essential oil

3.2 Performance evaluation of solar system for distillation process

Different experiments were conducted to evaluate the performance of the Scheffler reflector by recording receiver inside temperature, water & steam temperature and beam radiations. From these data, energy in sensible and latent heat phase were calculated by using Equation(1) and Equation(2) respectively.

$$Q_s = m_w\, c_p\, \Delta T/3600 \quad (1)$$

$$Q_L = x\, m\, h_{fg} /3600 \quad (2)$$

Where: Q_s = Sensible heat, kWh; m_w = Mass of water, kg; c_p = Specific heat at constant pressure (For water = 4.187 kJ/(kg・K)); ΔT = Temperature difference, K; Q_L = Latent heat, kWh; m_s = Mass of water evaporated, kg; h_{fg} = Specific latent heat of vaporization (For water = 2260 kJ/kg); x = Dryness fraction of steam.

Power (kW) is calculated by dividing these energy values with specific time interval (hours).

Figure 6 illustrates the variation of water temperature, receiver inside temperature and solar radiations on a sunny day of August 5, 2007 from 1,207 to 1,400 hours. In this performance evaluation test with 20 L of water, 2.005 L of water was evaporated.

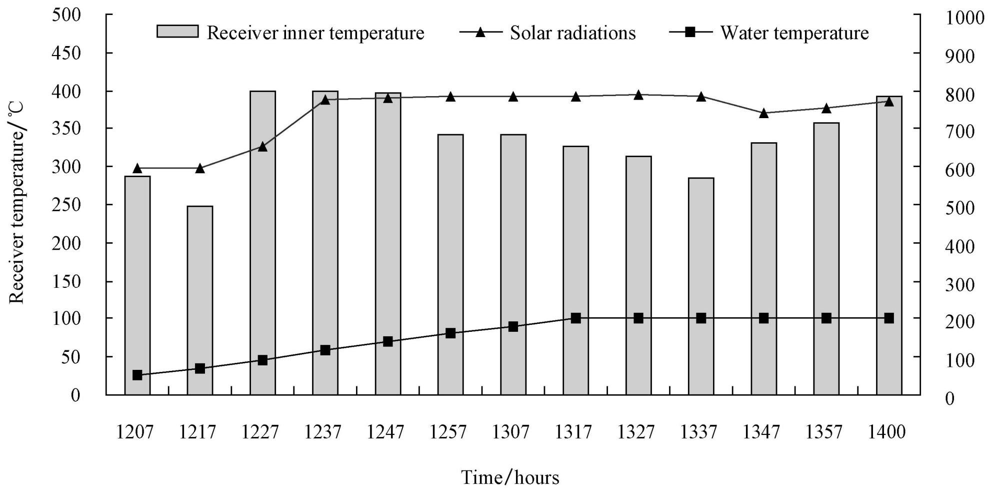

Figure 6 Variation of solar radiations, receiver inner temperature and water temperature

During this test, the average value of power in terms of water boiling test was calculated to be 1.58 kW. The system efficiency was calculated as 43.25% against an average value of beam radiations (739 W/m^2). This efficiency figure relates to the perfection of the reflector surface area, its reflectance, absorptance of the outer surface of the distillation tank exposed to radiations and insulation of the remaining surface. Another trial was made with cooking oil to see the maximum temperature of other liquids. In this test, there was uniform rise in temperature from 23℃ to 250℃ with respect to time and then the heavy vapor was observed phase transformation at high temperature. So it can be concluded that the Scheffler reflector can not only be used to evaporate the water but also equally good for processing other liquids and cooking oils.

3.3 Results of solar distillation system

Table 1 illustrates the complete distillation process for essential oils extraction using 400 g Cumin using solar energy.

The data were recorded for time, beam radiations (W/m^2), water temperature (℃), heat energy (kWh), essential oil extracted (mL) and percentage of total oil extracted. It is evident from Table 1 that there is constant increase in temperature with respect to energy up to 100℃ (sensible heat zone). Thereafter, the temperature line becomes parallel to abscissa till the end of the experiment. There is gradual increase in oil extraction in latent heat zone. Against energy level of 3.01 kWh, 100% of essential oil (4.06 mL) was extracted. After this limit, there was no rise in the level of oil. So 3.01 kWh is the optimum energy for the distillation process of 400 g Cumin. Although this experiment was conducted in the evening time of low solar radiations hours yet the temperature and energy obtained from the solar reflector were found quite satisfactory for distillation process of Cumin. The comparison of laboratory and solar distillation is shown in Figure 7.

Table 1 Different parameters recorded during solar distillation of 400 g Cumin on August 24, 2007

Time /hours	Beam radiations /W· m^{-2}	Water temperature /℃	Heat energy /kWh	Essential oil extracted /mL	Fraction of total oil /%
1,532	558	21	0.00	0.00	0.00
1,542	701	39	0.21	0.00	0.00
1,552	731	62	0.48	0.00	0.00
1,602	711	89	0.79	0.00	0.00
1,612	717	100	0.99	0.68	16.75
1,622	682	100	1.22	0.95	23.40
1,632	715	100	1.48	1.22	30.05
1,642	703	100	1.70	1.85	45.57
1,652	692	100	1.93	2.43	59.85
1,702	676	100	2.15	2.43	59.85
1,712	659	100	2.40	2.97	73.15
1,722	668	100	2.62	3.38	83.25
1,732	665	100	2.83	3.65	89.90
1,742	360	100	3.01	4.06	100
1,752	242	100	3.19	4.06	100

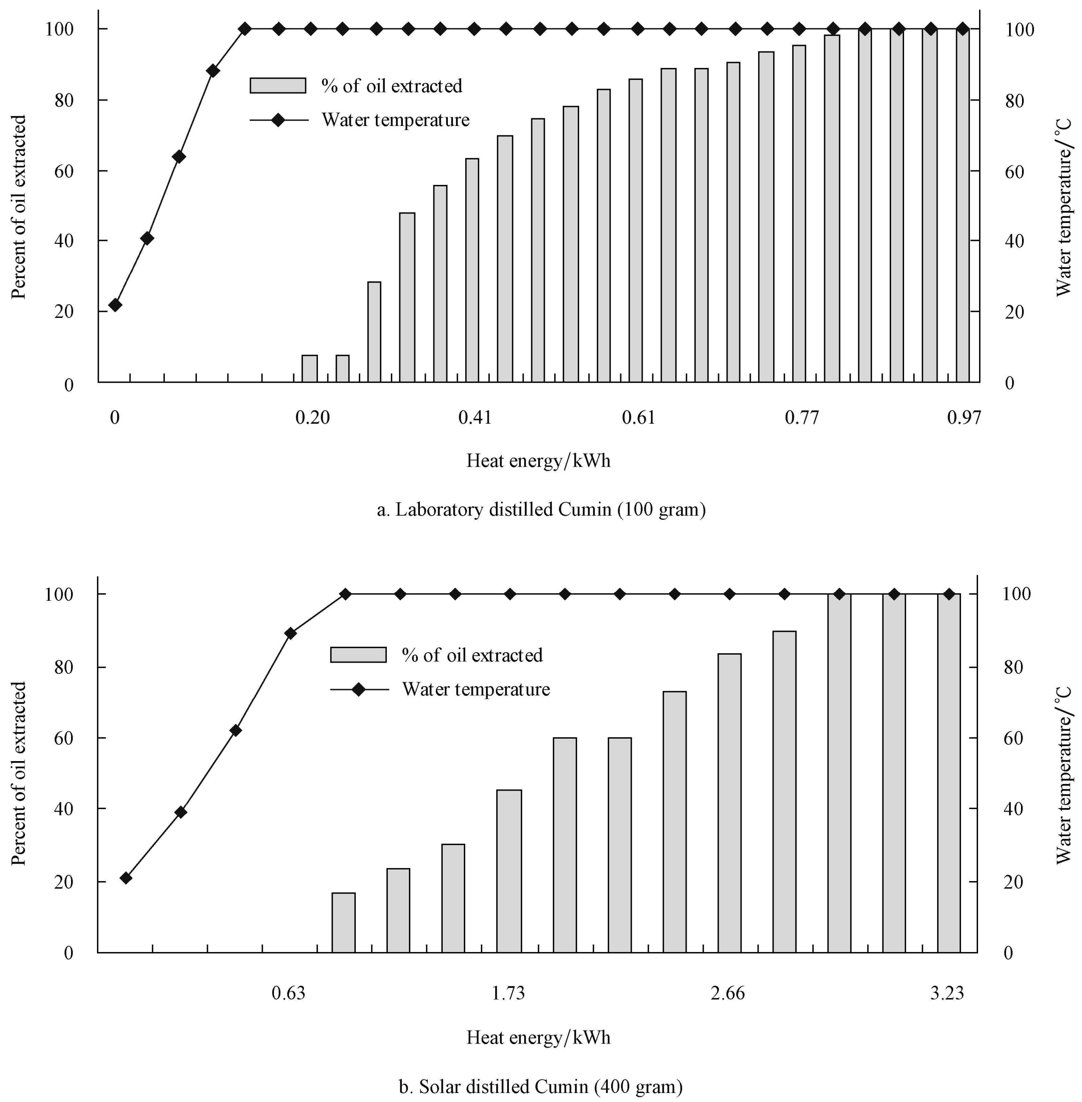

Figure 7 Process comparison of laboratory distillation and solar distillation system

Figure 7 shows that the process lines and oil extraction pattern of solar distillation system are quite similar to that of laboratory distillation. This result shows that solar energy can be best utilized by selecting an appropriate type of collector.

Several experiments were carried out for solar distillation system. For all experiments, successful results were achieved. While conducting solar experiments, laboratory experiments were also carried out simultaneously in the same conditions of the herbs for comparison. Comparison results of solar distillation system and laboratory experiments of some herbs are shown in the Table 2.

Table 2 Comparison of laboratory and solar distillation process for 100 g of Cumin, Cloves and Fennel

Herbs	Cumin		Cloves		Fennel	
	Laboratory	Solar	Laboratory	Solar	Laboratory	Solar
Oil Extracted (mL/100 g)	1.081	1.033	5.500	5.500	0.784	0.760
Energy Consumed (kWh/mL of oil)	0.574	0.719	0.133	0.176	0.503	0.476
Percent Decrease in Essential Oil	-	4.440	-	0	-	3.061
Percent Increase in Energy	-	25.260	-	32.330	-	5.368

Table 2 shows the quantity of essential oils per 100 g of herbs, energy consumption (kWh) per mL of oil, percent decrease in essential oils (compared with the laboratory) and percent increase in energy consumption. In the most of the experiments, the percent decrease in essential oil extraction by solar distillation was found up to 5% than that of laboratory. In some cases, almost the same results were also achieved. In several experiments, about 4%-8% energy consumption per unit weight of the herbs were observed as in case of Fennel (5.368%). However, more energy consumption was observed in some of the experiments as in case of Cumin (25.26%) and cloves (32.33%). This variation is due to undetermined factors as the solar experiments are conducted in open atmosphere. These factors are due to high wind velocity and fluctuations of solar radiations due to cloudy conditions. So the energy levels in solar distillation system vary from time to time depending on the climatic conditions etc. However, the oils extraction results in all experiments gave satisfactory results. These results show that distillation process for essential oils extraction can be done successfully using Scheffler reflector without any auxiliary energy. However, the solar system needs a little modification to enhance the extraction efficiency and lower energy consumption in adverse weather conditions.

4 Conclusions

The experimental results with laboratory and solar distillation system have been presented. Optimum energy consumptions to process 100 g of Cloves buds, Fennel, Cumin, Patchouli, and Orange bark were found to be 0.734, 0.394, 0.621, 0.440 and 0.379 kWh respectively. These figures provide useful information about process energy requirement to distill different weights of herbs. The heat energy consumptions to extract 1 mL of oil from Cloves buds, Fennel, Cumin, Patchouli and Orange barks were found to be 0.133, 0.503, 0.574, 2.716 and 2.807 kWh respectively. These results gave the true idea about heat energy consumption and weight of herbs needed to extract a specific volume of essential oils. These results also lead to developing solar distillation system. On a sunny day with an average global radiations figure of 739 W/m^2, the output power and system efficiency during distillation process using Scheffler fixed focus concentrator were calculated as 1.58 kW and 43.25% respectively. In the most of the experiments, extraction results by solar distillation were found similar to that of laboratory. The study concludes that solar distillation for essential oils extraction can be successfully carried out by Scheffler fix focus concentrator. These results provide decision making for farmers to adopt farming practices according to the amount of energy available at farm for extraction of essential oils from different herbs. However, more energy consumption was recorded using solar energy comparatively while processing various herbs. These excessive heat losses are due to undetermined factors like high wind velocity, fluctuations in solar radiations etc as the experiments were conducted in open atmosphere. The study suggests minor modifications in the existing distillation system to minimize the heat losses and to enhance extraction efficiency of the unit.

References

Balzar, A., P. Stumpf, S. Eckhoff, H. Ackermann, and M. Grupp. 1996. A solar cooker using vacuum-tube collectors with integrated heat pipes, *Solar Energy*, 58: 63－68.

Bhirud, N., and M. S. Tandale. 2006. Field evaluation of a fixed-focus concentrators for industrial oven. *Advances in Energy Research* (AER – 2006).

Bruce, S. 2001. Introduction to growing herbs for essential oils, medicinal and culinary purposes. *Crop & Food Research*, Number 45.

Delaney, D. 2003. Scheffler's community solar cooker, www.solar-bruecke.org.

Duffie, J., and W. Beckman. 2006. *Solar engineering of thermal process*, 3rd ed, Hoboken : John Wiley& Sons, Inc.

Esen, M. 2004. Thermal performance of a solar cooker integrated vacuum-tube collector with heat pipes containing different refrigerants. *Solar Energy*, 76: 751－757.

Fend, T., G. Jorgensen, and H. Küster. 2000. Applicability of highly reflective aluminium coil for solar concentrators. *Solar Energy*, 68: 361－370.

Garg, H. P., and J. Prakash. 2006. *Solar energy for industrial process heat, Solar energy fundamentals and applications*. Tata McGraw-Hill, New Delhi.

Goswami, D. Y., F. Kreith, and J. F. Kreider. 1999. *Principles of solar engineering*. 2nd ed. Philadelphia, PA: George H. Buchanan Co..

Malle, B., and H. Schmickl. 2005. *Ätherische Öle Selbst Herstellen*. Verlag die Werkstatt GmbH Lotzestraße 24 a, D-37083 Göttingen, p 23－27.

Morrison, G. L., J. Di, and D. R. Mills. 1993. *Solar stove for developed countries*. ed. E.Kaboldy, *Proceedings of ISES World Congress, August* 23-27, Budapest, Hungry: Hungarian Energy Society.

Öztekin, S., and M. Martinov. 2007. *Medicinal and aromatic crops, harvesting, drying and processing*. New York: Haworth Food & Agricultural Products Press™ , An Imprint of the Haworth Press, Inc.

Sharma, S. D., T. Iwata, and H. Kitano. 2005. Thermal performance of a solar cooker based on an evacuated tube collector with a PCM storage unit, *Solar Energy*, 78: 416－426.

Stumpf, P., and A. Balzar. 2001. Comparative measurements and theoretical modeling of a single - and double-stage heat pipe coupled solar cooking systems for high temperatures. *Solar Energy*, 71: 1－10.